Assessing Tensile and Shear Properties of Recycled Sustainable Asphalt Pavement

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ABSTRACT

Hot mix recycling of asphalt pavements is increasingly being used as one of the major rehabilitation methods by various highway agencies. Besides general savings in costs and energy expended, it also saves our natural resources and environment. Recycling process presents a sustainable pavement by using the old materials that could be reclaimed from the pavement; these materials could be mixed with recycling agents to produce recycled mixtures. The important expected benefits of recycling process are the conservation of natural resources and reduction of environmental impact. The primary objectives of this work are evaluating the Tensile and Shear Properties of recycled asphalt concrete mixtures, In addition to the resistance to moisture damage. The impact of implementing three types of recycling agents on asphalt concrete properties was also investigated. For this purpose, old materials reclaimed from field, (100% RAP), virgin filler at 3 percent content by weight of mixture and three types of recycling agents (soft asphalt cement of penetration grade 200-300, soft asphalt cement of penetration grade 200-300 blended with 4% silica fumes and soft asphalt cement of penetration grade 200-300 blended with 6% fly ash) at 1.5% content by weight of mixture have been implemented and used to prepare recycled mixtures. Mixtures were subjected to the following tests: Marshall Test (12 specimens), indirect tensile strength test at 20ºC, 25ºC, 40ºC, and 60ºC (48 specimens), indirect tensile ratio (12 specimens), double punch shear test (12 specimens).

It was found that using (soft asphalt cement blended with silica fumes) as a recycling agent revealed better performance results than the other type of recycling agent. The percentages of variation for recycled mixtures with recycling agent of (soft asphalt cement blended with silica fume) when compared to aged mixture were (-13.8%, -25.05%, 229.5%, -47.67%,) for properties of (Marshall stability, indirect tensile strength at 60ºC, tensile strength ratio, double punch test,), respectively.

Key words: recycled mixture, recycling agent, asphalt cement, silica fumes, flyash.

تقييم خصائص الشد والقص للرصفة الاسفلتية المستدامة المعاد تدويرها

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المستخلص

يعد التزايد في استخدام الخلطات الاسفلتية المعاد تدويرها احد الطرق الرئيسية في اعادة تأهيل الطرق من قبل وكالات الطرق السريعة، فهي بالإضافة الى كونها توفر التكاليف والطاقة المبذولة بشكل عام، فهي تحفظ الموارد الطبيعية والبيئية. ان عملية اعادة التدوير تقدم طبقة تبليط مستدامة عن طريق استخدام المواد القديمة التي يتم تهيئتها من هذه الطبقة وهذه المواد من الممكن مزجها مع معاملات اعادة التدوير لإنتاج خلطات الخرسانة الاسفلتية المعاد تدويرها. ان المنافع المتوقعة المهمة لعملية اعادة التدوير هي حفظ المصادر الطبيعية وتقليل التأثير البيئي.

الهدف من الدراسة هو تقييم خصائص الشد والقص لخلطات الخرسانة الاسفلتية المعاد تدويرها بالإضافة الى ذلك تقييم المقاومة لضرر الرطوبة، مع بحث تأثير استخدام ثلاثة انواع من مواد اعادة التدوير على خصائص الخرسانة الاسفلتية. لهذا الغرض فان المواد القديمة التي أحضرت من الموقع بنسبة 100% والمواد المالئة الناعمة الجديدة بنسبة 3% من وزن الخلطة وثلاثة انواع من مواد اعادة التدوير (الاسفلت السمنتي ذو درجة الاختراق 200-300 و الاسفلت السمنتي ذو درجة الاختراق 200-300 مع 4% غبار السيليكا و الاسفلت السمنتي ذو درجة الاختراق 200-300 مع 6% من الرماد المتطاير) عند محتوى معامل تدوير 1.5% من وزن الخلطة ، تم استخدامها لتحضير الخلطات المعاد تدويرها.

ان الخلطات في هذه الدراسة تم تعرضها للفحوص التالية : فحص مارشال (12 نموذج) وفحص مقاومة الشد غير المباشر في 20°م، 25°م، 40°م، 60°م (48 نموذج) ، فحص نسبة الشد غير المباشر (12 نموذج) ، فحص الاختراق المزدوج (12 نموذج).

لقد تم الاستنتاج بان استخدام مادة اعادة التدوير (الاسفلت السمنتي ذو تدرج الاختراق العالي + غبار السيليكا) يعطي افضل نتائج اداء من الانواع الاخرى من مواد اعادة التدوير. ان نسب التغاير في خواص الخلطات المعاد تدويرها باستخدام معامل اعادة التدوير (الاسفلت السمنتي ذو تدرج الاختراق العالي مع غبار السيليكا) مقارنة مع الخلطة المرجعية كانت (-13.8% ، -24.05% ، 229.5% ، -47.67%) لكل من خواص (ثبات مارشال ، مقاومة الشد غير المباشر في 60°م ، نسبة الشد غير المباشر ، فحص الاختراق المزدوج.

الكلمات الرئيسيه: خلطة معاد تدويرها، معامل تدوير، الاسفلت الاسمنتي، ابخرة السيليكا، الرماد المتطاير.

1. INTRODUCTION

Recycling is the process of reusing the existing pavement materials that no longer serve the traffic effectively. The recycling of pavements can be seen as a sustainable option, as it is a production process with environmental and economic benefits. When the pavement mixture reaches the end of its service life it may be disposed or recycled. Using Reclaimed Asphalt Pavement (RAP) is considered as an economical and environmental friendly process; it preserve the natural resources and could produce similar structural performance when compared with virgin asphalt mixtures **,Hussain and Yanjun, 2012.** Most of the local research work on recycling concentrates on the physical properties of recycled mixes; little attention has been paid on the durability issue of recycled mixes. In fact using RAP in pavement construction has now become common practice in many countries. In Iraq, most of asphaltic pavement needs maintenance or rehabilitation; therefore, asphalt pavement recycling could be suggested for maintenance, rehabilitation or even reconstruction process at economical basis with acceptable properties. The most important properties which should be investigated are the Tensile and Shear Properties of recycled asphalt concrete to improve serviceability, reduce maintenance costs and impair safe operations. This Properties is caused by the accumulation of permanent deformation in all or some layers in the pavement structure. In this work, a detailed investigation was carried out to evaluate the durability of recycled asphalt concrete in terms of Tensile and Shear Properties and resistance to moisture damage.

2. MATERIALS CHARACTERISTICS

2.1 Aged Materials

The reclaimed asphalt mixture was obtained by the rubblization of full depth asphalt concrete from highway section. This highway was constructed during 1982; the highway was heavily deteriorated with various cracks and ruts existed on the surface. The rubblized section involves asphalt stabilized base coarse layer and two layers of binder coarse. The reclaimed mixture was heated, combined and reduced to testing size as per AASHTO 2013; a representative sample was subjected to Ignition test according to AASHTO T 308 procedure to obtain binder and filler content, gradation and properties of aggregate. **Table. 1** presents the properties of aged materials after Ignition test while **Table. 2** presents gradation of old (reclaimed) aggregate obtained from aged mixture. It can be seen that the gradation is finer that that specified for the reclaimed layers (base and binder courses), this may be attributed to the possible degradation of aggregate under traffic through the pavement life.

2.2 Mineral Filler

Mineral filler used in this work is limestone dust obtained from factory in Holy Karbala governorate. The physical properties of the used filler are presented in **Table. 3.**

2.3 Recycling Agents

2.3.1 Soft grade asphalt cement

Asphalt cement of penetration grade 200-300 obtained from Al-Dura refinery was adopted for recycling in this work. Its physical properties are listed in **Table. 4.** Soft asphalt cement will be referred as "soft AC" in this study.

2.3.2 Soft grade asphalt cement blended with silica fumes

Asphalt cement of penetration grade 200-300 from Al-Dura refinery was blended with 4% of silica fumes which were obtained from local market based on **,Sarsam, 2013.** It is an ultra-fine powder consisting of nearly spherical particles around 100 times smaller than a grain of cement. Soft Asphalt was heated to nearly 110ºc, and the silica fumes were added gradually to the asphalt cement with stirring until homogenous blend was achieved; the mixing and stirring continued for 30 minutes by a mechanical blender. **Table. 5** shows physical properties of silica fumes while **Table. 6** presents physical properties of soft asphalt cement 200-300 blended with silica fumes. Soft asphalt cement blended with silica fume will be referred as "Soft AC+Silica fumes" in this work.

2.3.3 Soft grade asphalt cement blended with fly ash

Asphalt cement of penetration grade 200-300 from Al-Dura refinery was blended with 6% of Fly ash which was obtained from local market based on **,Sarsam, 2013.** Soft Asphalt was heated to nearly 110ºc, and the Fly ash was added to the asphalt cement gradually with stirring until homogenous blend was achieved. The mixing and stirring continued for 30 minutes by a mechanical blender. **Table. 7** shows physical properties of Fly ash while **Table. 8** presents physical properties of soft asphalt cement 200-300 blended with Fly ash. Soft asphalt cement blended with Fly ash will be referred as "Soft AC+Fly ash" in this work. **Fig. 1** shows recycling agent types and the mechanical blender adopted.

3. EXPERIMENTAL PROGRAM

3.1 Preparation of Mixtures

3.1.1 Reclaimed mixture (reference mixture)

Reclaimed mixture was obtained from the reclaimed material from field. It was heated to 145ºC and specimens were prepared for further testing to investigate the performance after recycling.

3.1.2 Preparation of recycled mixture

Recycled mixture consists of reclaimed mixture (RAP) 100%, virgin mineral filler and recycling agent mixed together at specified percentages according to the mixing ratio. First, RAP was heated to approximately 160ºC, mineral filler was heated to 160ºC. and recycling agent was heated to 130ºC separately before it was added to the heated RAP and filler at the desired amount; 3% by weight of mixture of the mineral filler was added and 1.5 % by weight of mixture of the recycling agents was added and mixed for two minutes until all mixture was visually coated with recycling agent as addressed by **,Sarsam, 2007.** The recycled mixture was prepared using three types of recycling agents: soft asphalt cement, soft asphalt cement blended with silica fume and soft asphalt cement blended with Fly ash.

3.1.3 Preparation of accelerated short term aged recycled mixture

Recycled mixtures was heated to 130°C to become loose and then spread in shallow trays with 3cm thickness and subjected to one cycle of accelerated aging process by storage inside an oven at 135°C for 4 hours as per Superpave procedure (**PP2**). The mix was stirred every 30 minutes during the short term aging process to prevent the outside of the mixture from aging more than the inner side because of increased air exposure. After the accelerated aging process was completed, Marshall Specimens were constructed from the aged asphalt concrete after heating the material to 150°C.

3.2 Preparation of Marshall Specimens

It is a cylindrical specimen of 102 mm in diameter and 63.5 mm in height. Marshall mold, spatula, and compaction hammer were heated on a hot plate to a temperature between 120-150ºC. A piece of non-absorbent paper, cut to size, was placed in the bottom of the mold before the mixture was introduced. The asphalt mixture was placed in the preheated mold, and then it was spaded vigorously with a heated spatula 15 times around the perimeter and 10 times around the interior. Another piece of non-absorbent paper cut to size was placed on the top of the mix. The temperature of mixture immediately prior to compaction temperature was 150ºC. The mold assembly was placed on the compaction pedestal and 75 blows on the top and the bottom of specimen were applied with specified compaction hammer of 4.535 kg sliding weight, and a free fall in 457.2 mm. The specimen in mold was left to cool at room temperature for 24 hours and then it was extracted from the mold using mechanical jack. Marshall Specimens were subjected to the following tests: Marshall Test (12 specimens), indirect tensile test at 20ºC, 25ºC, 40ºC, and 60ºC (48 specimens), indirect tensile ratio (12 specimens) and double punch test (12 specimens). **Fig. 2** presents a group of prepared specimens.

3.3 Laboratory Evaluation for Asphalt Concrete

3.3.1 Resistance to plastic flow (Marshall test)

This method covers the measurement of the resistance to plastic flow of cylindrical specimen of asphalt paving mixture loaded on the lateral surface by mean of the Marshall apparatus according to ASTM D 1559. The cylindrical specimen was conditioned by placing it in water bath at 60ºC for 30 minute, then it was inserted into the testing device, and compressed on the lateral surface with a constant load rate of 50.8 mm/min until the dial gage reached the maximum load resistance which is recorded as stability, and the corresponding flow value at that point was also recorded. The entire test was performed within 30 sec after the specimen was removed from water bath. Three specimens for each combination were tested and the average results were reported. **Fig. 3** shows Marshall Test Device.

3.3.2 Indirect tensile strength test and temperature susceptibility

The indirect tensile strength followed the procedure of ASTM D6931-07; Marshall Specimens were used in this test, and percent of air voids for specimens was the same as that for Marshall test. After the specimen was cooled at room temperature for 24 hours, it was conditioned by placing in water bath at four different temperatures 20, 25, 40, and 60 ºC for 30 minutes and then the specimen were centered on the vertical diametrical plane between the two parallel loading strips 12.7 mm in wide. Vertical compressive load at rate of 50.8 mm/min by Versa tester machine was subjected until the dial gage reading reached the maximum load resistance; the reason of conducting this test is to evaluate the tensile strength and temperature susceptibility for the mixtures. **Fig. 4** presents Indirect Tensile Test Device. The indirect tensile strength was calculated by the following equation: ASTM D4123

$$ITS = \frac{2000 * P}{\pi * T * D} \qquad (1)$$

where:
ITS = indirect Tensile Strength, kPa
P = maximum load resistance at failure, N
D = diameter of specimen, mm
T = thickness of specimen immediately before test, mm

The temperature susceptibility was calculated by the following equation: **Husham, 1999**

$$\boldsymbol{TS = \frac{(ITS)t1 - (ITS)t2}{t2 - t1}} \qquad (2)$$

where:
TS = temperature susceptibility (kPa / ºC)
(ITS)t1= indirect tensile strength at t1 =25ºC
(ITS)t2 = indirect tensile strength at t2 =40ºC

3.3.3 Indirect tensile strength ratio test

The test was performed to evaluate the moisture damage resistance of mixtures, and the procedure followed ASTM D4867. A set of six specimens were prepared, three specimens were tested for indirect tensile strength by storing in a water bath at 25ºC for 30 minutes, and an average value of ITS for these specimens was computed as SI (ITS for unconditioned specimens). The other three specimens were conditioned by placing in volumetric flask 4000-ml heavy- wall glass filled with water at room temperature 25˚C and then a vacuum of 28mm Hg was applied for 5 to 10 min. to obtain 55 to 80 % degree level of saturation. The specimens were then placed in deep freeze at -18˚C for 16 hours. The frozen specimens then were moved to a water bath for 24 hours at 60ºC. Then they were placed in a water bath at 25ºC for 1 hour, and they were tested for indirect tensile strength. The average value was computed as SII (ITS for moisture-conditioned specimens). **Fig. 5** shows the process of conditioning of specimens for

TSR test .The indirect tensile strength ratio could be calculated from the following equation: ASTM D4867

$$TSR = \frac{SII}{SI} * 100 \qquad (3)$$

Where:
TSR = indirect tensile strength ratio, %
SI= average ITS for unconditioned specimens, kPa
SII = average ITS for moisture-conditioned specimens, kPa

3.3.4 Double punch shear test
This test procedure was developed at the University of Arizona by Jimenez 1974, and it was used to measure the stripping of the binder from the aggregates. This test was reported by many studies **,Solaimanian, 2004. ,Turos, 2010. ,Sarsam, 2006. and ,Hasan, 2012.** Marshall specimen was used for this test; it was conditioned by placing in water bath at 60ºC for 30 min. The test was performed by centrally loading the cylindrical specimen, using two cylindrical steel punches placed on the top and bottom surface of the sample. The specimen was centered between the two punches 2.54cm in diameter, perfectly aligned one over the other, and then loaded at a rate of 2.54cm /minute until failure. The reading of dial gage at the maximum load resistance was recorded. **Fig. 6** shows Double Punch test apparatus. The punching strength is computed by the equation:

$$\sigma t = \frac{p}{\pi(1.2bh - a^2)} \qquad (4)$$

where:
σt = punching stress, Pa
P= maximum load, N
a= radius of punch, mm
b=radius of specimen, mm
h=height of specimen, mm

4. ANALYSIS AND DISCUSSION OF TEST RESULTS

4.1 Marshall Stability

It was found that recycling decreases Marshall stability, as the stability value was high for aged mixture (19.2 kN), it decreased for recycled mixtures with (Soft Ac), (Soft Ac + Silica Fume) and (Soft Ac + Fly ash) recycling agents by (-17.45%, -13.8% and -5.73%) respectively compared with aged mixture. This may be attributed to the fact that aged mixture contains hardened asphalt, which will lead to increased stability due to higher asphalt viscosity, while recycled mixtures lack necessary bonding effect because of their reduced viscosity (increased workability) and increased binder content (after adding the rejuvenator). This agrees well with the findings of **,AL-Zubaidi, 2013.** Mixtures with recycling agents (Soft Ac) showed lower stability than (Soft Ac + Silica Fume), and (Soft Ac + Silica Fume) showed lower stability than (Soft Ac + Fly ash), which indicates that bonding effect for (Soft Ac + Fly ash) is higher than the other agents. Variation in the stability of mixtures is presented in Figure (4-2). Also it can be seen from **Fig. 7** that all mixtures has stability value more than (8 kN) which represent stability of surface layer according to the specification limits of roads and bridges SCRB, 2003.

4.2 Marshall Flow

Recycling revealed a pronounce increase in Marshall flow value corresponding to aged mixture. All the types of recycled mixtures satisfied Marshall flow criteria of (2-4) mm, except recycled mixture with (Soft Ac). Flow value for mixture with (Soft Ac) was higher than other mixtures. While the Flow value for mixture with (Soft Ac + Silica Fume) was lower than other mixture. **Fig. 8** clarifies the flow results.

4.3 Effect of Recycling Agent Types on Indirect Tensile Strength (ITS)

Mixtures were subjected to indirect tensile strength test at 20ºC, 25ºC, 40ºC, and 60ºC. Three specimens for each mixture type were tested, and the average value was obtained to represent the tensile strength of this type at the specified temperature. Also, the temperature susceptibility for each mixture type was obtained.

Recycling revealed a pronounce increase in (ITS) value at 20˚C corresponding to aged mixture. The percent of increase in (ITS) for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) was (10.86%, 24.58% and 29%) respectively as compared with aged mixture. **Fig. 9** presents the (ITS) values at 20ºC.

Results indicated that tensile strength at 25ºC for all the recycled mixtures was lower than aged mixture value by (-39.62%, -31.57% and -15%) for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) respectively as compared with aged mixture. Also Mixtures with recycling agent of (Soft Ac) showed lower indirect tensile strength value than that with (Soft Ac + Silica Fumes). On the other hand, mix with (Soft Ac + Silica Fumes) shows lower indirect tensile Strength value than that with (Soft Ac + Fly ash). **Fig. 10** presents the (ITS) values at 25ºC.

The reduction in Tensile strength values at 40ºC for recycled mixtures was higher than that of aged mixture. The percent of reduction in (ITS) value for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) was (-33.31%, -22.63% and -6.93%) respectively when compared with aged mixture. The recycled mixture with (Soft Ac + Fly ash) revealed the highest tensile strength value as compared to other recycled mixtures, but it was lower than (ITS) value of aged mixture.

At 60ºC, the tensile strength for aged mixture was higher than that of recycled mixtures. The percentages decrease in (ITS) value for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) was (-38.53%, -25.05% and -4.21%) respectively. The recycled mixture with (Soft Ac + Fly ash) had higher tensile strength value than other recycled mixtures. **Fig. 11** presents the (ITS) values at 40ºC and **Fig. 12** presents the (ITS) values at 60ºC.

The reduction in (ITS)value at (25˚C, 40˚C and 60˚C) for recycled mixtures are in contrast with the findings of **,Hasan, 2012.**

The temperature susceptibility results presented in **Fig. 13** shows that recycled mixtures were less influenced by temperature than aged mixture by (-49.52%, -45.56% and -27.75%) for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) respectively. Mixture with (Soft Ac) revealed the lower temperature susceptibility value than other recycling agents. Mixture with (Soft Ac + Fly ash) was higher than both mixtures with (Soft Ac + Silica Fume) and (Soft Ac) in temperature susceptibility. This might be caused by the properties of the (Silica Fumes and Fly ash), as these agents are more influenced by temperature variation than asphalt cement. The temperature susceptibility value for aged mixture was high due to the nature of aged and hardened asphalt cement which leads to a mixture more susceptible to temperature variation. **Fig. 13** shows the temperature susceptibility results.

4.4 Effect of Recycling Agent Types on Tensile Strength Ratio (TSR)

The results of tensile strength ratio showed that recycled mixtures had good resistance to the action of water. The tensile strength ratio was higher than 80% for all recycled mixtures **Fig. 14**, and the recycled mixture with (Soft Ac) had the highest (T.S.R) value comparing to other recycled mixtures, while mixture with (Soft Ac + Fly ash) was lower than both mixtures with (Soft Ac + Silica Fume) and (Soft Ac) in (TSR). The results revealed high improvement in tensile strength for recycled mixtures with (Soft Ac, Soft Ac +Silica Fumes and Soft Ac + Fly ash) by (241.65%, 229.5% and 192.61%) compared to aged mixture. This agrees well with the findings of **,Hasan, 2012.**

4.5 Effect of Recycling Agent Types on Punching Shear Strength

Double punch test indicates the stripping behavior between binder and aggregate, and since recycled mixture contains recycling agent which has a softening effect in the mixture, the stripping behavior was the concern of the study. The punching shear strength for recycled mixtures was lower than aged mixture by (-48.47%, -47.67% and -10.35%) for recycled mixtures with (Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash) respectively and this agrees with the findings of **,AL-Zubidi, 2013.** This might be related to the lower viscosity of binder in recycled mix compared to aged mix. Recycled mix with (Soft Ac + Fly ash) had the highest punching shear strength value compared to the other recycled mixtures, and recycled mix with (Soft Ac) revealed the lowest value. **Fig. 15** presents double punch test results for recycled and aged mixtures.

5. CONCLUSIONS

1. Significant reduction in Marshall Stability was noticed for recycled mixtures when compared to aged mixture. The percent of reduction was (-17.45%, -13.8% and -5.73%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash, respectively.
2. Significant improvement in indirect tensile strength at 20˚C was noticed for recycled mixtures as compared to aged mixture. While (ITS) at 25˚C, 40˚C and 60˚C revealed low value for recycled mixtures when compared to aged mixture. The percent improvement in (ITS) value at 20˚C was (10.86%, 24.58% and 29%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash, respectively. While the percent reduction in (ITS) value at 25˚C was (-39.62%, -31.57% and -15%), and at 40˚C was (-33.31%, -22.63 and -6.93%) and at 60˚C was (-38.53%, -25.05% and -4.21%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash , respectively.
3. The results of tensile strength ratio showed that recycled mixtures had good resistance to moisture damage by (241.65%, 229.5% and 192.61%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash, respectively as compared with aged mixture.
4. Punching shear strength for recycled mixtures was lower than that of aged mixture by (-48.47%, -47.67% and -10.35%) for recycled mixtures with Soft Ac, Soft Ac + Silica Fumes and Soft Ac + Fly ash, respectively.

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Table 1. Properties of reclaimed materials after ignition test

Material	**Property**		**Value**
Asphalt binder	Binder content %		4.94%
Coarse aggregate	Bulk specific gravity		2.56
	Apparent specific gravity		2.619
	Water absorption %		1.057%
	Wear% (Los Angeles abrasion)		22%
Fine aggregate	Bulk specific gravity		2.590
	Apparent specific gravity		2.819
	Water absorption %		1.91%
Mineral filler	Percent passing sieve no.200		98%
	Specific gravity		2.82
Aged Mixture	Marshall Properties	Stability	19.2 kN
		Flow	3.3 mm
		Air voids	6.14%
		Bulk density	2.322 gm/cm^3

Table 2. Gradation of old (reclaimed) aggregate obtained from aged mixture.

Sieve no.	**Sieve size (mm)**	**% Passing by weight**	**SCRB Specification**	
			Base course	**Binder or leveling cours**
1½"	37.5	-----	100	----
1"	25.4	100	90-100	100
3/4"	19	99	76-90	90-100
1/2"	12.5	94	56-80	70-90
3/8"	9.5	85	48-74	56-80
No.4	4.75	61	29-59	35-65
No.8	2.36	49	19-45	23-49
No.50	0.3	19	5-17	5-19
No.200	0.075	4	2-8	3-9

Table 3. Physical properties of filler (lime stone).

Property	Value
Bulk specific gravity	2.87
% Passing sieve no.200	99

Table 4. Physical properties of soft asphalt cement recycling agent.

Property	**Test conditions**	**ASTM Designation no.**	**Value**
Penetration	25°c, 100gm, 5sec	D5-06	260
Softening point	(ring & ball)	D36-95	36
Ductility	25°c, 5cm/min	D113-99	80
After thin film oven test properties D1754-97			
Retained penetration of residue	25°c, 100gm, 5sec	D5-06	51%
Ductility of residue	25°c, 5cm/min	D113-99	45
Loss on weight	163°c, 50g,5 hrs		0.37

Table 5. Physical properties of silica fumes.

Property	**Value**
specific gravity	2.14
% Passing sieve no.200	100
Specific surface area (m^2/ kg)	20000

Table 6. Physical properties of soft asphalt cement (200-300) blended with 4% silica fumes.

Property	**Test conditions**	**ASTM Designation No.**	**Value**
Penetration	**25°c, 100gm, 5sec**	D5-06	253
Softening Point	**(ring & ball)**	D36-95	38
Ductility	**25°c, 5cm/min**	D113-99	105
After Thin Film Oven Test Properties D1754-97			
Retained penetration of residue	**25°c, 100gm, 5sec**	D5-06	47%
Ductility of residue	**25°c, 5cm/min**	D113-99	35
Loss on weight	**163°c, 50g,5 hrs**		0.22

Table 7. Physical properties of fly ash.

Property	**Value**
specific gravity	2.0
% Passing sieve no.200	99%
Specific surface area (m^2/ kg)	650

Table 8. Physical properties of soft asphalt cement (200-300) blended with 6% fly ash.

Property	**Test conditions**	**ASTM Designation No.**	**Value**
Penetration	**25°c, 100gm, 5sec**	D5-06	278
Softening point	**(ring & ball)**	D36-95	34
Ductility	**25°c, 5cm/min**	D113-99	65
After Thin Film Oven Test Properties D1754-97			
Retained penetration of residue	**25°c, 100gm, 5sec**	D5-06	35%
Ductility of residue	**25°c, 5cm/min**	D113-99	22
Loss on weight	**163°c, 50g,5 hrs**		0.27

Figure 1. Recycling agents type and mechanical blender.

Figure 2. Group of prepared specimens.

Figure 3. Marshall test at NCCLR laboratory.

Figure 4. Indirect tensile test device.

Figure 5. Conditioning process of specimens for TSR test at NCCLR laboratory.

Figure 6. Double punch test apparatus.

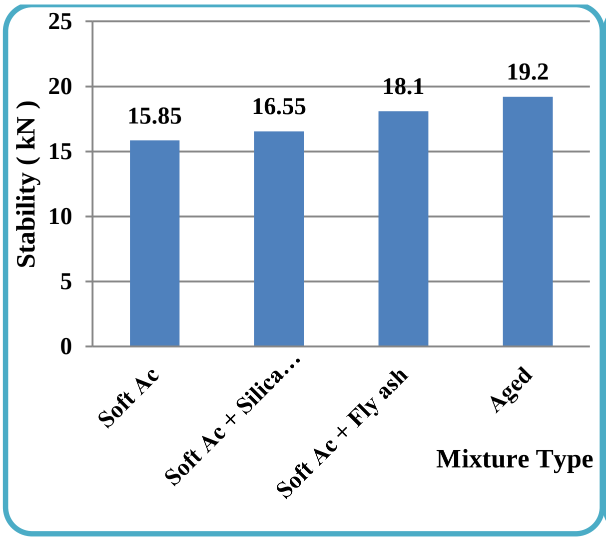


Figure 7. Stability for aged and recycled mixtures.

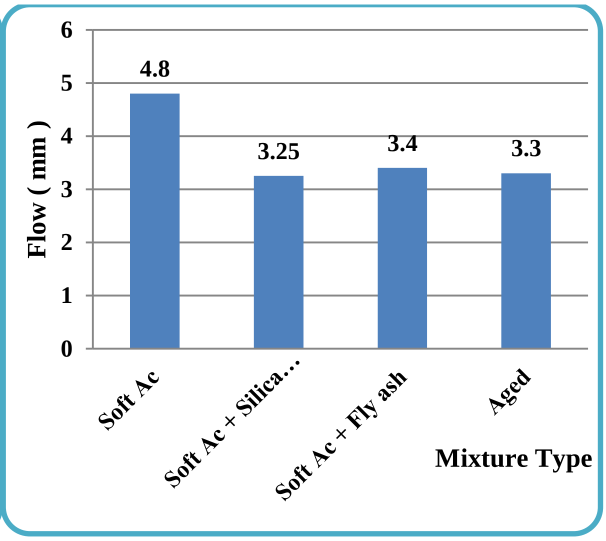


Figure 8. Flow results for aged and recycled mixtures.

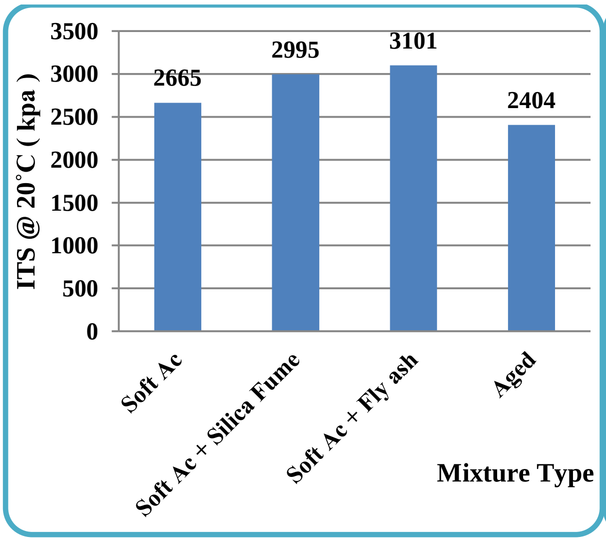


Figure 9. ITS Results at 20˚C for aged and recycled mixtures.

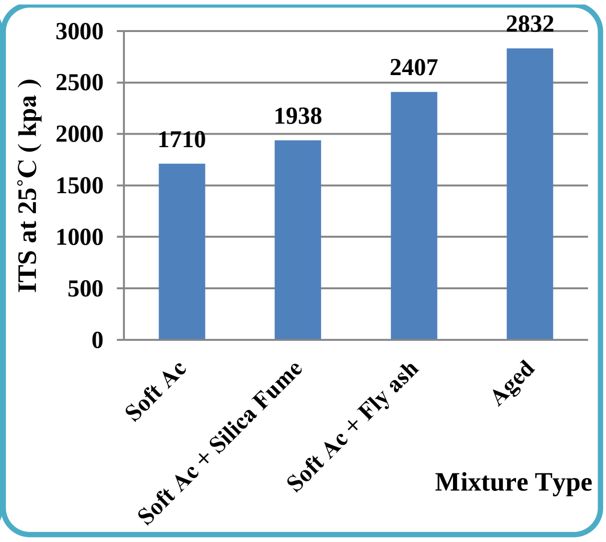
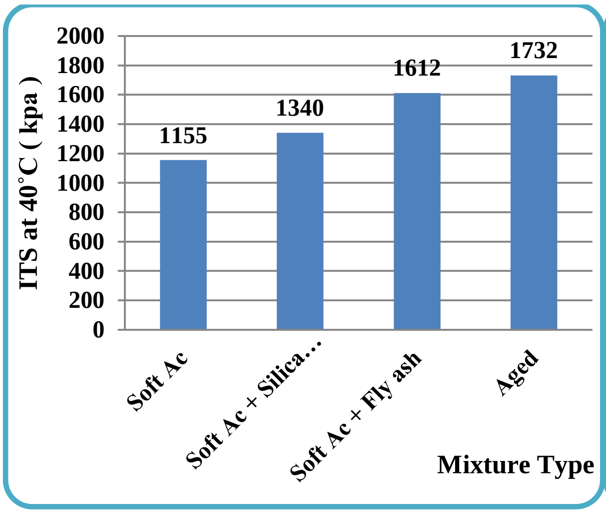


Figure 10. ITS Results at 25˚C for aged and recycled mixtures.



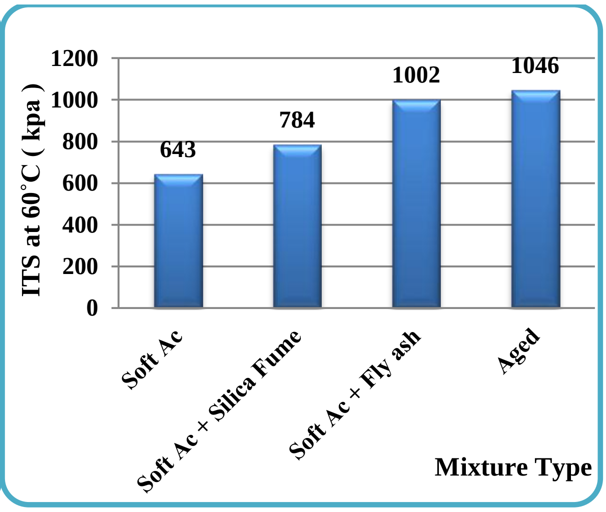
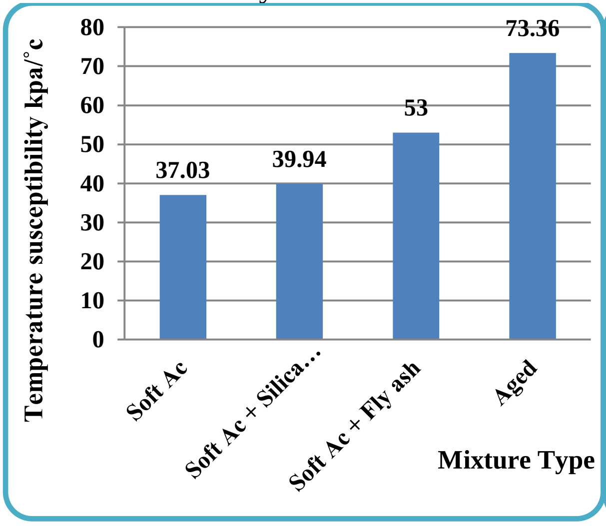


Figure 11. ITS Results at 40˚C for aged and recycled mixtures.

Figure 12. ITS Results at 60˚C for aged and recycled mixtures.



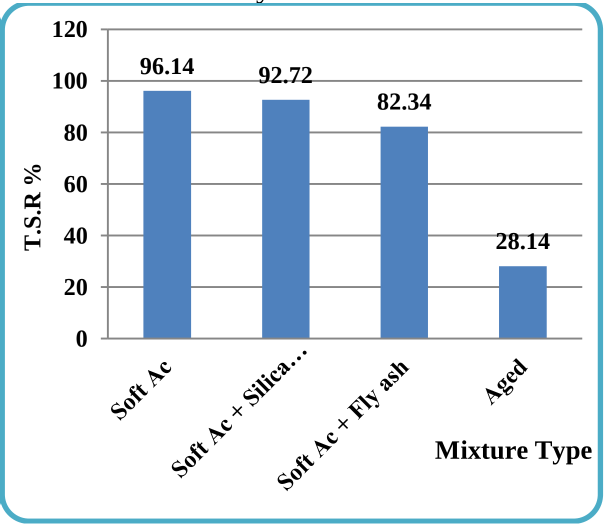


Figure 13. Temperature susceptibility results for aged and recycled mixtures.

Figure 14. Tensile strength ratio test for aged and recycled mixtures.

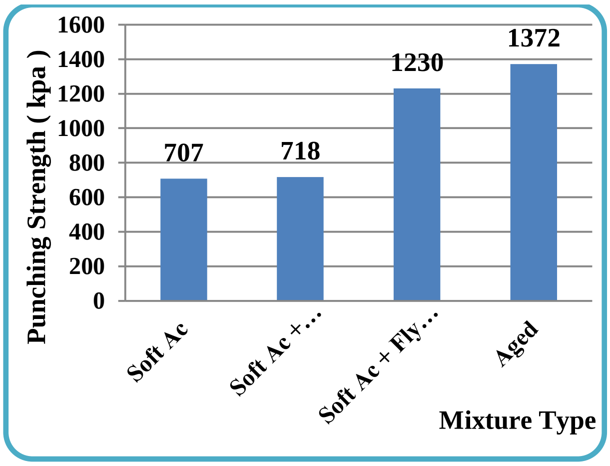


Figure 15. Double punch test results for aged and recycled mixtures.